

# Measurement of the D meson elliptic flow in Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV with ALICE

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## Abstract

We present the measurements of  $D^0$ ,  $D^+$ ,  $D^{*+}$  meson  $v_2$  as well as  $D^0 R_{\text{AA}}$  in different directions with respect to the estimated reaction plane in Pb–Pb collisions at  $\sqrt{s_{\text{NN}}} = 2.76$  TeV with the ALICE detector at the LHC.

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## 1. Introduction

On the basis of thermodynamical considerations and Quantum Chromo-Dynamics (QCD) calculations, nuclear matter, in conditions of high temperature and density, is expected to undergo a phase transition to a deconfined state: the Quark Gluon Plasma (QGP) [1]. These conditions can be recreated in high energy nucleus–nucleus collisions.

Non-central nucleus–nucleus collisions are characterized by an initial geometrical anisotropy with respect to the reaction plane (the plane defined by the beam direction and the impact parameter). As a consequence of the different pressure gradients in the in-plane and out-of-plane regions, this spatial anisotropy is converted to a momentum anisotropy of produced low- $p_{\text{T}}$  particles. The momentum anisotropy can be quantified via a Fourier expansion of the azimuthal angle with respect to the estimated reaction plane. The second coefficient of this expansion  $v_2$  is called elliptic flow [2]. The azimuthal anisotropy of heavy-flavour hadron production is sensitive to the degree of thermalization of heavy quarks in the expanding medium and to the path length dependence of their energy loss [3, 4, 5, 6, 7, 8].

## 2. Data sample and event plane determination

The D meson azimuthal anisotropy measurements presented in this report are performed with the ALICE detector [9] using the 2011 data sample collected with a minimum bias trigger given by the coincidence of signals in the VZERO scintillators and the Silicon Pixel Detector (SPD) and a trigger tuned to enhance the sample of 50% most central collisions, based on the VZERO signal amplitude, which is used to classify the events according to centrality. The analyses have been performed with  $9.5 \times 10^6$  Pb–Pb collisions in the centrality class 30–50%,  $7.1 \times 10^6$  in 15–30% and  $16 \times 10^6$  in 0–7.5%.

The azimuthal direction of the event plane, which estimates the reaction plane direction, is determined from the distribution of charged tracks in the  $0 < \eta < 0.8$  pseudo-rapidity interval

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<sup>1</sup>A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

of the Time Projection Chamber (TPC) using the equation

$$\Psi = \frac{1}{2} \tan^{-1} \left( \frac{\sum_{i=0}^N w_i \sin 2\varphi_i}{\sum_{i=0}^N w_i \cos 2\varphi_i} \right), \quad (1)$$

where  $\Psi$  is the second harmonic event plane and  $\varphi_i$  is the angle of the  $i^{\text{th}}$  track in the ALICE reference frame. The event plane resolution ( $R_2$ ) was computed considering each event as splitted in 2 sub-events, made of randomly combined tracks and associated to the correspondent event plane angle, following the prescription in [10]. The resulting event plane is flat to about 2% level and its resolution is 0.86 in the 30–50% centrality class, 0.9 in 15–30% and 0.75 in 0–7.5%.

### 3. D meson reconstruction, $v_2$ and $R_{AA}$ determination

D meson reconstruction in ALICE is based on the invariant mass analysis of fully reconstructed hadronic decay topologies of these channels:  $D^0 \rightarrow K^- \pi^+$ ,  $D^+ \rightarrow K^- \pi^+ \pi^+$  and  $D^{*+} \rightarrow D^0 \pi^+$ . The separation of about a few hundred  $\mu\text{m}$  between the primary and the secondary vertices, peculiar of  $D^0$  and  $D^+$  decay, is exploited to reduce the combinatorial background. In ALICE, charged tracks are reconstructed with a six layers silicon tracker (Inner Tracking System) and the Time Projection Chamber (TPC). In particular, the Silicon Pixel Detector (SPD) provides a measurement of track impact parameter to the primary vertex with a resolution better than  $65 \mu\text{m}$  for tracks with  $p_T > 1 \text{ GeV}/c$ . Particle identification is provided by the time of flight measurement in the Time-Of-Flight detector for kaons with  $p_T < 2 \text{ GeV}/c$  and by the specific energy deposit in the TPC. For high- $p_T$  particles, a selection is applied in order to reject protons without losing possible kaons. The contribution of signal candidates with wrong mass assignment to the final state hadrons was found to be negligible and it does not bias the signal extraction. Further details on the analysis can be found in [11]. The invariant mass distribution of reconstructed D meson candidates is considered in the in-plane and out-of-plane regions defined as  $\left[0 < \Delta\varphi < \frac{\pi}{4}\right) \cup \left[\frac{3\pi}{4} < \Delta\varphi < \pi\right)$  and  $\left[\frac{\pi}{4} < \Delta\varphi < \frac{3\pi}{4}\right)$  respectively, where  $\Delta\varphi$  is the azimuthal angle of the reconstructed candidate with respect to the event plane  $\Psi$ . An invariant mass analysis, based on a Gaussian fit, is used to obtain the signal yield in the two regions ( $N_{\text{IN}}$ ,  $N_{\text{OUT}}$ ). Assuming that the reconstruction and selection efficiency is independent of  $\Delta\varphi$ , it is possible to directly compute the elliptic flow from the formula (2, left), where  $R_2$  is the event plane resolution.

$$v_2 = \frac{\pi}{4} \frac{1}{R_2} \frac{N_{\text{IN}} - N_{\text{OUT}}}{N_{\text{IN}} + N_{\text{OUT}}}, \quad R_{AA}(p_T) = \frac{dN_{AA}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}/dp_T} \quad (2)$$

The  $R_{AA}$  measurement is based on the comparison between the yield measured in AA collisions and the cross section measured in pp collisions, scaled by the overlap nuclear function, as shown in formula (2, right). For this analysis, the yields  $N_{\text{IN}}$  and  $N_{\text{OUT}}$  were corrected for acceptance and efficiency as a function of  $p_T$ , using PYTHIA + HIJING Monte Carlo simulations [12]. Details on the correction for the secondary D meson and the pp measurement, used as reference, can be found in [12].

Several sources of systematic uncertainties were considered in both analyses. The main contributions come from uncertainties on the yield extraction and from the topological cut selection. The former is estimated using different background functions in the fitting procedure, different mass range, and a bin counting method. The analysis was also repeated with three different sets of topological cuts. Yield extraction and cut variation systematic uncertainties are estimated to be at maximum 0.05 absolute value, for the  $v_2$  analysis. The signal sample considered contains

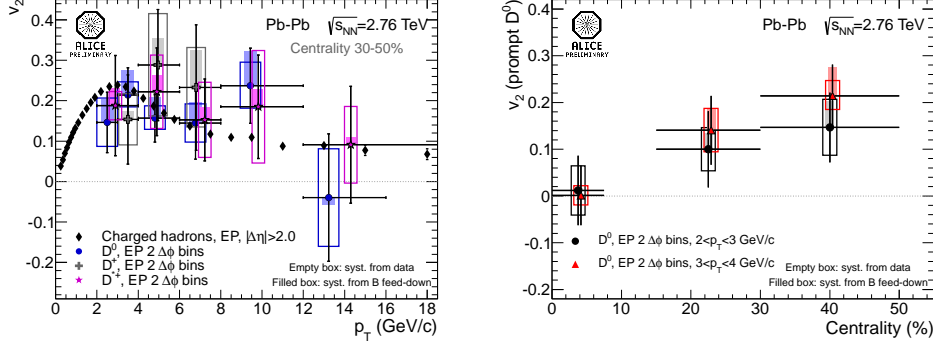


Figure 1: (left)  $D^0$ ,  $D^+$  and  $D^{*+}$   $v_2$  measured by ALICE in the 30-50% centrality class. Empty boxes show systematic uncertainties from data and the shaded area the B feed-down one. Black points shows the charged hadron  $v_2$ . (right)  $D^0$   $v_2$  as a function of centrality for the bins  $2 < p_T < 3$  GeV/c,  $3 < p_T < 4$  GeV/c. Empty boxes show systematic uncertainties from data and the shaded areas the B feed-down one.

a fraction of D mesons coming from B decays, thus the measured elliptic flow is a combination of prompt and secondary D meson anisotropy. The feed-down correction uses as input pQCD calculations of B production, as explained in [11]. The resulting systematic uncertainty on  $v_2$  is up to +23%, including a conservative variation of the unknown  $R_{AA}$  and  $v_2$  of D meson from B decays. The centrality dependence of the event plane resolution in the centrality range considered was also taken into account, together with the uncertainty on the resolution. For the 30-50% centrality class, these uncertainties were found to be  $\pm 3\%$  and  $+7\%$  respectively. The small difference of efficiencies in the two  $\Delta\phi$  region was found to give a negligible contribution to the  $v_2$  uncertainties.

#### 4. Results

The D meson anisotropy was measured in the 30–50% centrality class: for  $D^0$  in the range  $2 < p_T < 16$  GeV/c,  $D^+$  in  $3 < p_T < 8$  GeV/c and  $D^{*+}$  in  $2 < p_T < 20$  GeV/c. The three results are compatible within statistical uncertainties and all are compatible with the ALICE measurement of charged hadrons in the same rapidity region (Fig. 1, left). The  $D^0$   $v_2$  measurement was also performed in the centrality classes 15–30% and 0–7.5% in the range  $2 < p_T < 16$  GeV/c. The results for the first two  $p_T$  intervals show a hint of increasing  $v_2$  from central to semi-peripheral collisions, as reported in Fig.1, right.  $v_2$  was measured using two-particles correlation methods as well. The results are consistent with those based on the event plane. The measurement of the D meson anisotropy was compared to theoretical predictions [13]: it was observed that a simultaneous description of the anisotropy and of the  $R_{AA}$  suppression is challenging for models.

The  $D^0$   $R_{AA}$  in the two azimuthal regions, in-plane and out-of-plane, was measured in the range  $2 < p_T < 16$  GeV/c. The measurement shows more suppression in the out-of-plane region with respect to the in-plane one, suggesting a path length dependence of heavy quark energy loss, which is expected to be the dominant effect at high  $p_T$  (Fig. 2). At low  $p_T$ , elliptic flow may also contribute to the observed anisotropy. In Fig. 2 we compare the  $D^0$   $R_{AA}$  in the two azimuthal regions with theoretical predictions. The WHDG [14] and POWLANG [5] models show a good agreement with out-of-plane results while they somewhat oversuppress the in-plane yields. This

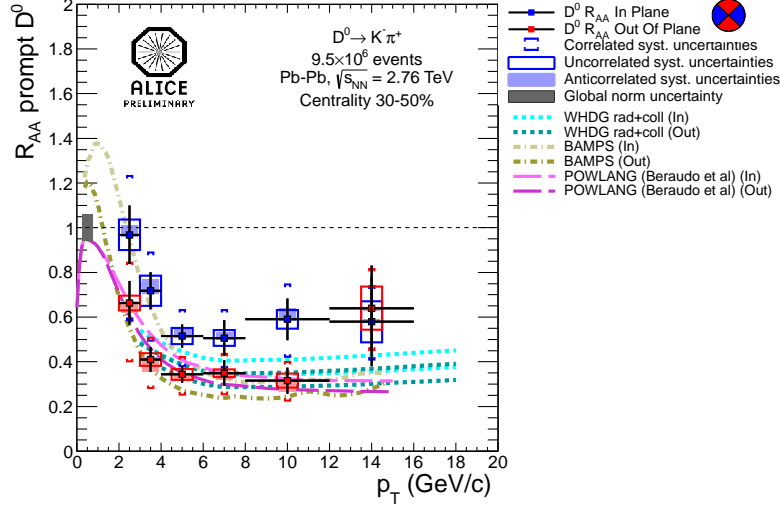


Figure 2:  $D^0 R_{AA}$  vs event plane for the 30–50% centrality class. Empty boxes show the uncorrelated systematic uncertainties between the two measurements, the empty brackets the correlated systematic uncertainties that would shift both measurements in the same direction and shaded areas the anticorrelated uncertainties that would shift the measurements in opposite directions.

high- $p_T$  feature is present also for the BAMPS model [7], which instead can describe the data in the low- $p_T$  range.

## 5. Conclusions

The measurement of D meson  $v_2$  in Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV with ALICE was presented. The results indicate  $v_2 > 0$  in the  $p_T$  range  $2 < p_T < 6$  GeV/c with a  $3\sigma$  significance in the 30-50% centrality class. A hint of centrality dependence is observed. The measurement of the  $D^0 R_{AA}$  around two orthogonal directions with respect to the event plane, in the 30–50% centrality class, indicates a larger suppression in the out-of-plane direction, where the initial overlap region of the two nuclei is more elongated, suggesting a path length dependence of heavy-quark energy loss.

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